A *Pseudo-nitzschia* Bloom in Penn Cove, Washington During the Summer 1997

Vera L. Trainer, Nicolaus G. Adams, Brian D. Bill, Bernadita F. Anulacion and John C. Wekell

National Marine Fisheries Service, Northwest Fisheries Science Center, Environmental Conservation Division

Introduction

The first documented toxic algal bloom caused by a diatom was in 1987 off the coast of eastern Prince Edward Island, Canada (Bates et al., 1989). The excitatory neurotoxin, domoic acid (DA), produced during this episode resulted in death or acute intoxication of many humans following their ingestion of contaminated blue mussels (Bird et al., 1988; Wright et al., 1989). Since 1991, the Washington Department of Health (WDOH) has been measuring DA seasonally in razor clams collected on the Washington coast, sometimes at levels above the regulatory limit (Horner et al., 1996). The agency has also implemented a routine monitoring program for DA in the inland waters of Puget Sound utilizing existing sentinel mussel stations supplemented by monitoring of commercial shellfish species.

We were alerted in early July 1997 by WDOH officials to elevated levels of DA in commercial mussels provided for monitoring by a shellfish farm located on the eastern side of Whidbey Island. This commercial mussel farm, which supplies mussels year-round to many coastal regions of the U.S., was established in Penn Cove due to the unique hydrographic and geographic features of the embayment that make it the most prolific mussel farming area in the state. The geography of the eastward-facing cove makes it a poorly flushing nutrient trap for the outflow of the Skagit River system. This factor combined with high amounts of sunshine in the area due to the rain-shadow effect of the Olympic Mountains turns Penn Cove into a “bay of plankton soup.” The appearance of blooming phytoplankton in the cove at some time during early summer months for the past several years (Ian Jefferds, Penn Cove Mussels, pers. comm.) makes it an ideal location for the study of environmental influences on bloom initiation, concentration and dispersal. Our measurements of physical and biological parameters and their correlations with *Pseudo-nitzschia* species abundance during July and August 1997 at several sites within Penn Cove, Whidbey Island, and in neighboring waters of Saratoga Passage are detailed in this paper.

Materials and Methods

Field Sampling

Sampling at five stations, approximately 50 m offshore (solid circles, see Figure 1) in Penn Cove, Whidbey Island, was at three depths (0, 5, 15 m). Three surface stations (open circles) were also sampled within the cove. Beginning August 5th, surface stations near or outside the mouth of the cove (open circles) were also sampled to measure spreading into Saratoga Passage.

Depth, temperature, and salinity were obtained with a SeaCat SBE19 (Sea-Bird Electronics, Inc., Bellevue, WA) conductivity-temperature-depth profiler. Five-meter and 15-m water samples were collected using 2.5-L Niskin bottles. Surface samples were collected by bucket. Sub-samples from the Niskin bottle were processed as described below for *Pseudo-nitzschia* cell counts. Station locations were determined using a hand-held global positioning system (Magellan 5000D).

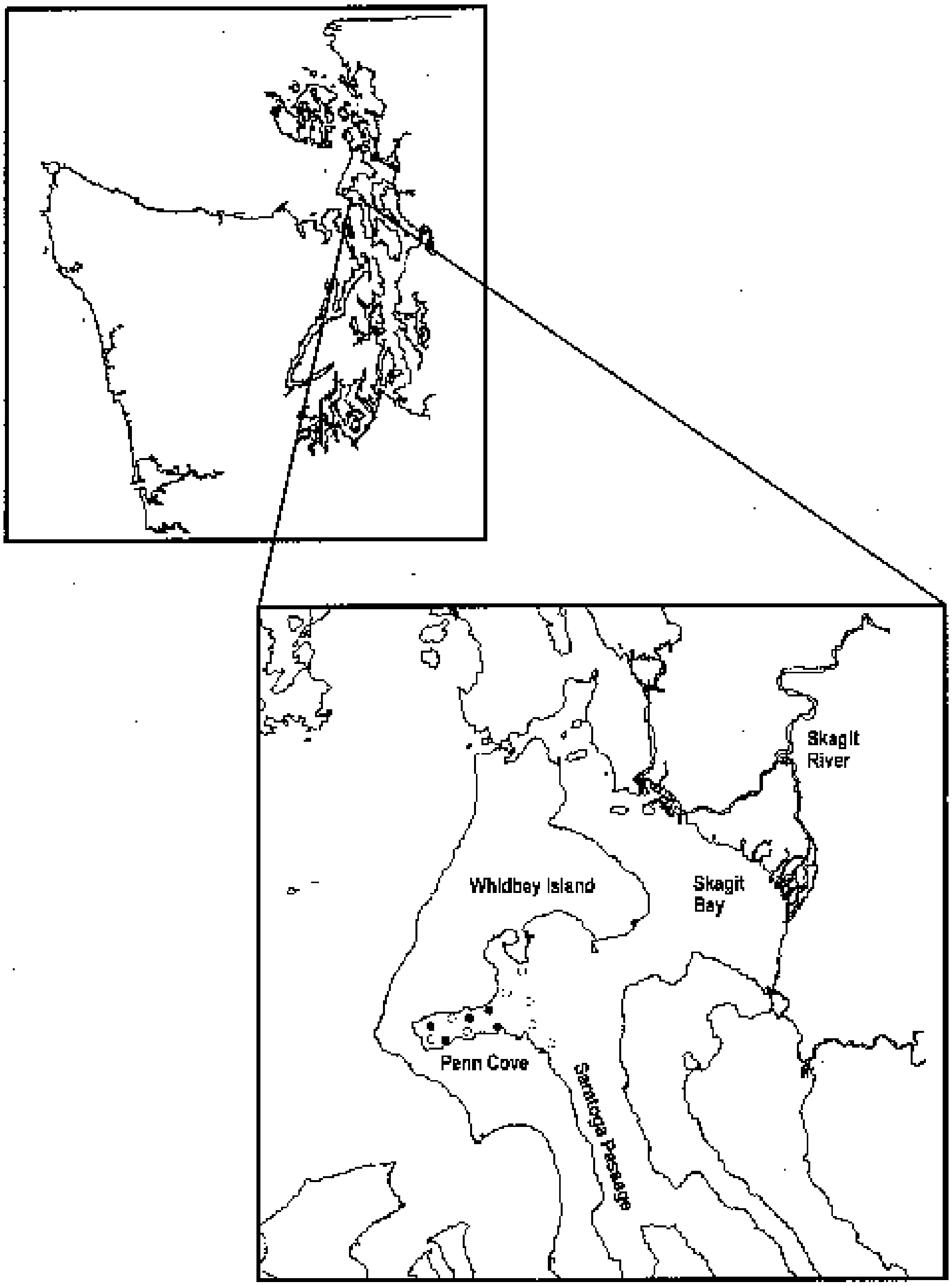

Figure 1. Sampling locations in Penn Cove, Washington.

Laboratory Analyses

Phytoplankton samples were collected using 0.25 m diameter nets having a mesh size of 20 µm. Cells were identified to the genus level and counted using light microscopy. Shellfish toxicity data for mussels collected from Penn Cove was made available by the WDOH.

Results and Discussion

Algal blooms of *Pseudo-nitzschia*, *Chaetoceros*, and *Noctiluca* have been observed in Penn Cove in the early summer over the past few years, several days after a shift of winds to a southeasterly direction (Ian

Jefferds, pers. comm.). In 1997, conditions were favorable again for a phytoplankton bloom in Penn Cove, which was first observed during early July (M. Kirkpatrick, WDOH, pers. comm.). The presence of *Pseudo-nitzschia* species as a dominant component of the bloom was confirmed in a water sample obtained from the cove on July 10th. The levels of DA in mussels harvested from Penn Cove reached a maximum of 3 ppm (μg/g) on July 6th and 10th (Table 1). These high levels were accompanied by winds that shifted from a westerly to a S/SE direction on July 7–10 at a maximum speed of 10 knots on July 8th (Figure 2).

Table 1. Domoic acid levels in Penn Cove mussels.

Sampling Date	Domoic Acid
June 29	< 1 ppm
July 6	3 ppm
July 10	3 ppm
July 13	2 ppm
July 23	< 1 ppm
July 27	NTD

NTD = no toxin detected
ppm = parts per million
Data were provided by WDOH.
Measurements made after July 27th were NTD.

Daily observations of current movement indicated that wind and rainfall were the primary factors that influenced mixing within the cove (Ian Jefferds, pers. comm.). The highest average wind speeds for the three-month period from June–August were measured on July 1st at above 15 knots. Average air temperature (_C) showed a general rising trend during the early part of July in comparison to the latter part of June (Figure 2). Heavy rains experienced in June and the early part of July ended for a several week period beginning on July 10th. Discharge from the Skagit River was above average volumes (USGS Water Information System, historical data), especially during the time from June 17–18 and July 9–12 due to periodic summer warming trends (Figure 2) and uncommonly high levels of snowfall earlier in the year resulting in necessary release of water from upstream dams.

High winds and rains experienced on July 1st may have facilitated mixing of the water column, thereby delivering nutrients from depth to the surface, especially in shallower areas on the western edge of the cove. The increase in surface runoff and winds blowing into the cove from a S/SE direction beginning on July 7th may have subsequently initiated a period of stratification, setting the stage for a sustained algal bloom in the poorly-flushed cove. A period of hot, calm summer weather (average daily air temperatures at 14–16 _C and average daily wind speed of less than 10 knots) after July 10th further stabilized the water column and intensified stratification. On July 28th, the maximum number of *Pseudo-nitzschia* cells were associated with relatively low salinity water of 24–25 ppt, which was above highly stratified waters. On this date, high numbers of *Pseudo-nitzschia* cells, up to 13 million cells/L, were observed above the thermocline at 2 m. The buoyant plume of low salinity water at the mouth of the cove, likely resulting from the massive volume of Skagit River runoff on July 9–12, appeared to direct the position of cells, moving them into the shallower waters toward the western end of the cove. Previous association of an isolated patch of toxic algae with low salinity water has been documented in a bloom of the dinoflagellate *Alexandrium* off the southwest Gulf of Maine (Franks and Anderson, 1992; Franks, 1990). This buoyancy front was formed by the upper bending of the halocline at the mouth of the cove, which separates the lighter surface water from the dense deep water. The warm, fresher water formed a thin lens on the upper 2–3 m throughout the cove, even near the western edge as evidenced in the vertical profile plot. Similar vertical profiles were observed at all stations throughout the cove on July 28th. In summary, factors contributing to strong stratification of the water column on this date included a neap tide on July 26th, sunshine, and freshwater input into the cove.

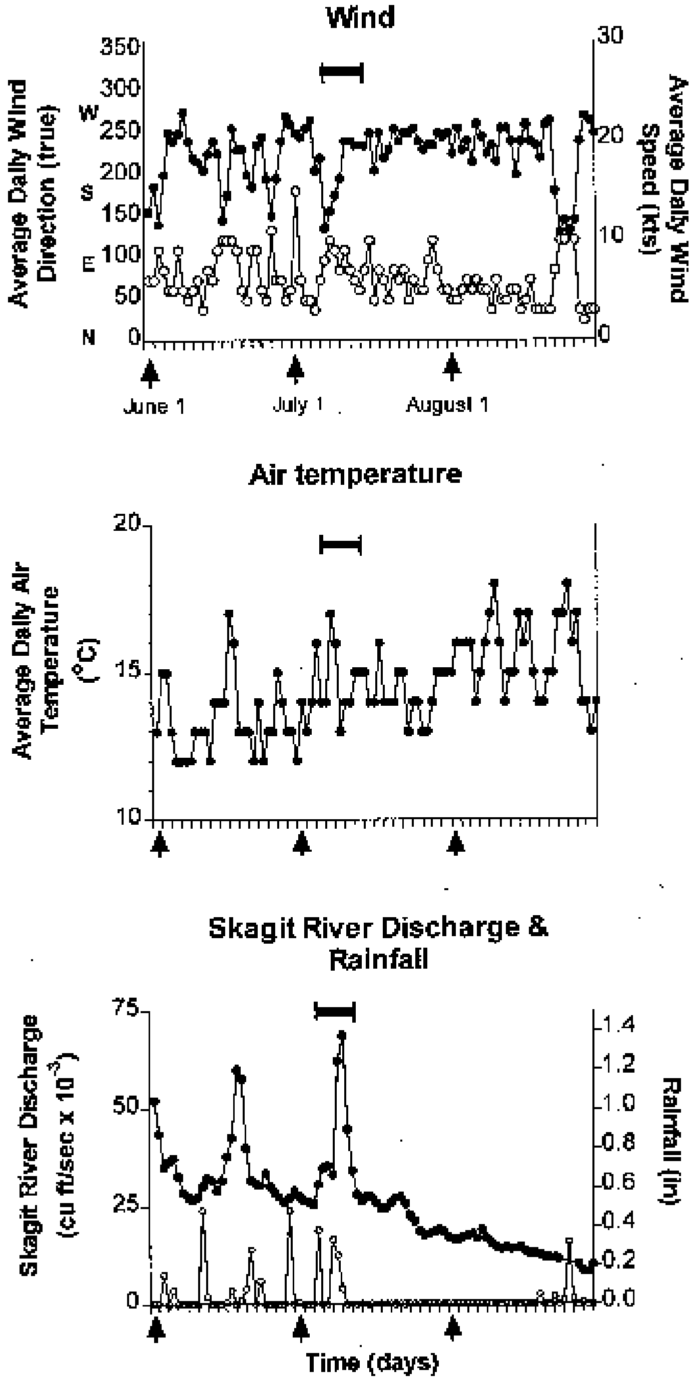

Figure. 2. Environmental data during June, July, and August 1997 at locations near Penn Cove, Washington. Skagit River discharge data (closed circles) is measured at Mount Vernon, a United States Geological Survey Water Information Station about 30 km northeast of Penn Cove, and approximately 11 km from the point of discharge into Skagit Bay. Wind direction (solid circles) and speed (open circles), air temperature, and rainfall data (open circles) are obtained from the Whidbey Island Naval Air Station National Climatic Data Center (NOAA), which is located about 10 north of Penn Cove. Daily averages were computed from hourly measurements during a 24-hour period. Bars above each graph indicate the period of maximum DA levels in Penn Cove mussels.

On August 5th, the vertical profile changed dramatically. Stratification decreased substantially causing relaxation of the buoyancy front. As a result, a large proportion of the total *Pseudo-nitzschia* were mixed to all depths at the mouth of the cove. In contrast, on the west side, all measurable *Pseudo-nitzschia* were in surface waters above the thermocline at approximately 2 m. Maximum cell number, which decreased about five-fold from July 28th to approximately 3 million *Pseudo-nitzschia* cells/L on August 5th, were found at the western edge and also at the mouth of the cove.

One week later, on August 12th, cell numbers of *Pseudo-nitzschia* increased to a maximum of 4 million cells/L, as a dense patch of cells became entrained below the halocline to reach a maximum at 5 m. This entrainment appeared to be directed by a buoyant plume of low salinity surface water. In comparison to the previous week, surface water warming and increased stratification were observed on this date. Contributing to this stratification were low average wind speed, relatively high average daily air temperatures, and a neap tide on August 11th.

On August 21st, the inner locations of the cove were completely mixed, with a small freshwater lens observed at the mouth again due to exchange with fresher waters of Saratoga Passage. Rain on August 20th, winds shifting periodically to a southerly direction during the two weeks prior to this date, and a spring tide on August 18th facilitated the mixing of the cove. Total *Pseudo-nitzschia* dropped to a maximum of 700,000 cells/L, located at the center of the cove as a surface patch. Most cells were unhealthy (noted as thinning and colorless or fading chloroplasts) especially a localized band of cells that were measured at the western edge of the cove at 15 m depth. Gentle mixing of the cove during mid-August and small fluctuations of tides may have caused some of the cells the were at 5 m depth on August 12th to be entrained to 15 m on August 21st.

A movement of *Pseudo-nitzschia* from nutrient-poor surface waters into the higher-nutrient mixed layer was observed over the period of sampling from July to August. This may be a strategy that allows basal metabolism of *Pseudo-nitzschia* cells to occur at depth, where temperature and light intensities are low. These factors may enable enough *Pseudo-nitzschia* to survive at depth for several months until conditions for bloom formation are ideal.

Conclusions

In June and July 1997, massive volumes of Skagit runoff due to abundant snow melt facilitated the flow of lowland drainage, bringing nutrient-rich fresh waters to neighboring embayments, including Penn Cove. The combination of nutrient-rich runoff, rain, and high south to southeasterly winds in early July followed by lighter winds, sunshine, and a neap tide resulted in prime conditions that allowed *Pseudo-nitzschia* species several days of uninterrupted growth to build their standing stock to bloom proportions. A buoyant lens of fresh water strongly influenced the position of the bloom, especially during neap tides on July 28th and August 12th when mixing within the cove was minimal. Less stratification was evident on sampling dates closer to spring tides (August 5th and August 21st), especially toward the western (inside) edge of the cove, possibly due to advection of less-stratified water from Saratoga Passage. This advection of cells within a buoyant plume, common to algal blooms in shallow seas (Franks, 1992), resulted in entrainment of isolated patch of unhealthy cells to a depth of 15 m on August 21st.

This study of the concentration and dispersal of a *Pseudo-nitzschia* bloom in Penn Cove provides some predictive elements of toxic bloom occurrence in embayments within Puget Sound. Elements of this model include factors that contribute to initiation, concentration, and dispersal of the *Pseudo-nitzschia* bloom. These factors include:

Initiation

1. high runoff from the Skagit River,
2. high winds and rain, and
3. increased air temperature;

Concentration

1. dramatic shift of winds to a southeasterly direction,
2. subsequent sustained light winds,
3. sunshine, and
4. neap tides or reduced mixing;

Dispersal

1. possible depleted nutrients, and
2. exchange of Penn Cove water with Saratoga Passage water, predominantly during spring tides.

Long-term observation of *Pseudo-nitzschia* bloom phenomena in Penn Cove and other Puget Sound locations will further document the mechanism of bloom initiation and dispersal in this unique system of saltwater embayments.

Acknowledgements

We thank several of the staff of the Environmental Conservation Division, including D. Lomax, B. French, C. Shipek, L. Chicchelly, S. Sol, C. Hatfield, C. Bucher, and G. Yanagida, for helping with field work. We gratefully acknowledge the microscopy of *Pseudo-nitzschia* spp. performed by Dr. Rita Horner of the University of Washington.

References

Bates SS, Bird CJ, de Freitas ASW, Foxall R, Gilgan M, Hanic LA, Johnson GR, McCulloch AW, Odense P, Pocklington R, Quilliam MA, Sim PG, Smith JC, Subba Rao DV, Todd ECD, Walker JA, Wright JLC (1989): Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from eastern Prince Edward Island, Canada. Can J Fish Aquat Sci 46:1203–1215.

Bird CJ et al. (1988) Identification of domoic acid as the toxic agent responsible for the PEI contaminated mussel incident. Atlantic Research Laboratory Tech Rep 56:NRCC 29083. p.86.

Franks PJS (1990): Dinoflagellate blooms and physical systems in the Gulf of Maine. Ph.D. thesis, MIT/WHOI Joint Program in Oceanography, Woods Hole, Mass.

Franks PJS (1992): Phytoplankton blooms at fronts: patterns, scales, and physical forcing mechanisms. Rev Aquat Sci 6:2:121–137.

Franks PJS, Anderson DM (1992): Alongshore transport of a toxic phytoplankton bloom in a buoyancy current: *Alexandrium tamarense* in the Gulf of Maine. Mar Biol 112:153–164.

Horner, RA, Hanson, L, Hatfield, CL, Newton, JA (1996): Domoic acid in Hood Canal, Washington, USA. Yasumoto T et al. (eds): "Harmful and Toxic Algal Blooms" UNESCO, pp. 127–129.

Wright JLC, Boyd RK, deFreitas ASW, Falk M, Foxall RA et al. (1989): Identification of domoic acid, a neuroexcitatory amino acid, in toxic mussels from eastern Prince Edward Island. Can J Chem 67:481–490.